# A Comparison of the Quality Factors of Impedance Matched Electrically Small Wire Antennas

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**Abstract:** In this paper, the quality factors of several impedance matched, electrically small wire antennas are compared. The antennas considered have the same height, similar occupied volume and are designed to be self-resonant at the same frequency. The antennas are then impedance matched to a nominal 50 Ohm feed line. The quality factors of the antennas are compared as a function of impedance matching technique and antenna geometry. It is shown that the quality factors of the antennas are essentially the same, and, for the most part, independent of the matching technique and differences in the antenna geometry.

**Keywords:** Small Antennas, Quality Factor, Monopole Antennas

## 1. The Impedance Matched Random Geometry Wire Antenna

The first antenna considered is the random geometry wire antenna depicted in Fig. 1. The antenna is base fed and mounted over an infinite, perfectly conducting ground plane. It has an overall height of 6 cm and a maximum diameter of 4 cm. The wire diameter is 0.5 mm. For the purposes of this work, the antennas are considered to be lossless. Considering lossless antennas allows us to directly compare the inherent radiation properties of the antenna structure, which can be masked by wire loss. At the same time, the practical significance of wire loss cannot be discounted because the impedance and quality factor of an antenna are directly affected by and will differ as a function of loss within the antenna material.

The impedance of the random geometry antenna was computed over a frequency range of 50 MHz through 500 MHz. The antenna is self-resonant at a frequency of approximately 408 MHz ($h \sim 0.082\lambda$) with a resonant resistance of 3.8 Ohms. This antenna can be impedance matched to 50 Ohms at the self-resonant frequency using a number of techniques. These include using a short-circuit matching stub, as shown in Fig. 2a, and using a reactive L and C matching network at the feed point as shown in Fig. 2b. Both of these impedance matching techniques "transform" the resonant resistance of 3.8 Ohms to 50 Ohms as illustrated in Fig. 3. The values of the lossless L and C in the reactive network were not specifically set to align the two impedance curves over a wider range of frequencies.

Under these different impedance matching conditions, the two antennas have essentially identical resonant (matched) impedance, radiation pattern and efficiency characteristics. The question considered here is whether the two impedance matching techniques result in significantly different antenna quality factors or *Q*. The quality factor of the antennas is determined using the following expression [1]

 

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$$Q \approx \frac{w}{2R}\sqrt{\left(\frac{dR}{dw}\right)^2 + \left(\frac{dX}{dw} + \left|\frac{X}{w}\right|\right)^2} \tag{1}$$

where $R$ and $X$ are the feed point resistance and reactance of the antenna. A comparison of the quality factors of the unmatched and matched antennas is presented in Fig. 4. From Fig. 4, it is evident that the quality factors near the match frequency (≈ 408 – 410 MHz) are not significantly different for any of the configurations. The quality factors of the two impedance matched configurations are essentially identical near the match frequency and they are not much different from the quality factor of the unmatched antenna configuration at this frequency. Impedance matching the antenna did not significantly improve the quality factor of the antenna.

## 2. The Quality Factor of Different Geometry Antennas

In the previous section, it was shown that impedance matching the random geometry wire antenna with a short-circuit stub or reactive network did not significantly improve or change the quality factor of the antenna. In this section, the quality factors of impedance matched antennas with differing geometries are considered. The short-circuit stub matched antennas are depicted in Fig. 5. They include a meander line antenna, a normal mode helix antenna and an antenna of random geometry (different than that of Fig. 1). All of the antennas have an overall height of 6 cm and a wire diameter of 0.5 mm. Unmatched, they are designed to be self-resonant at the same frequency of approximately 408 MHz. The unmatched and matched impedance of these antennas are presented in Figs. 6 and 7, respectively. Since all of the antennas occupy the same height, they exhibit almost identical unmatched resonant resistance.

All of the antennas are impedance matched near 408 MHz using a short-circuit stub and they exhibit almost identical impedance, which is not unexpected since their unmatched impedances are very similar. A comparison of the quality factors of the impedance matched antennas is presented in Fig. 8. It can be seen that the quality factors of these impedance matched antennas are virtually identical near the match frequency and therefore, are essentially independent of the differences in antenna geometry.

## 3. Discussion

Antennas of the same height, wire diameter, and similar occupied volume, can be made self-resonant at the same frequency by adjusting the total wire length within the antenna structure. The total wire length will differ as a function of geometry. When made self-resonant at the same frequency, the antennas exhibit essentially the same resonant properties, which are primarily established by the antenna's height and effective volume. The quality factors are very similar for the different impedance matched antenna geometries since the quality factor of an antenna is primarily established by the antenna's height and effective volume relative to the resonant wavelength.

## References

[1] "Impedance, Bandwidth and Q of Antennas," A. D. Yaghjian and S. R. Best, *2003 APS Conference*, Vol. 1, pp. 501-504, Columbus, Ohio, June 2003

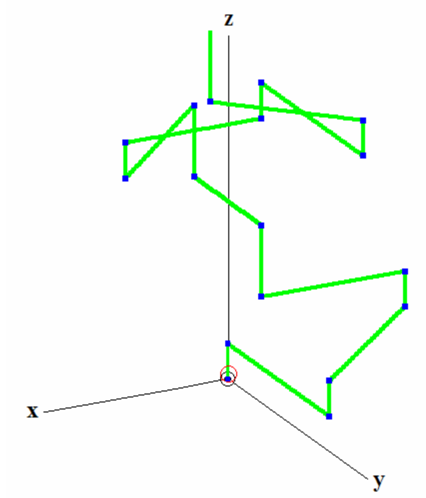


**Fig. 1. Depiction of the random geometry wire antenna.**

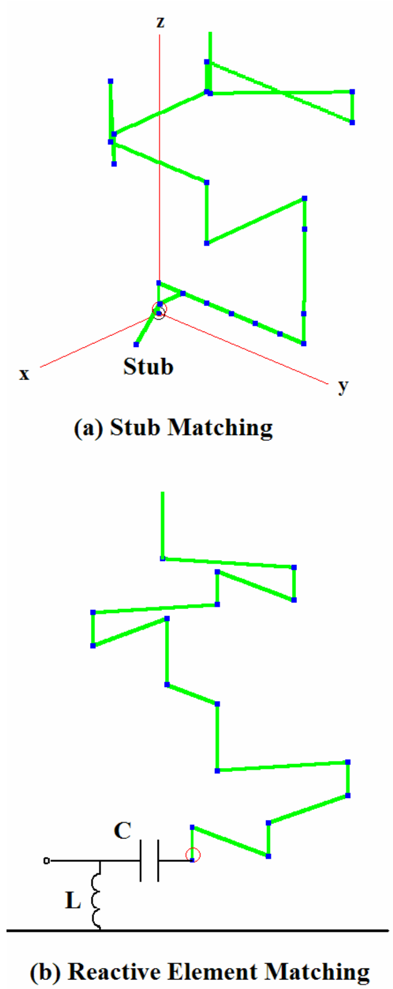


**Fig. 2. Depiction of the random geometry wire antenna with (a) short-circuit stub impedance matching and (b) reactive element network impedance matching.**

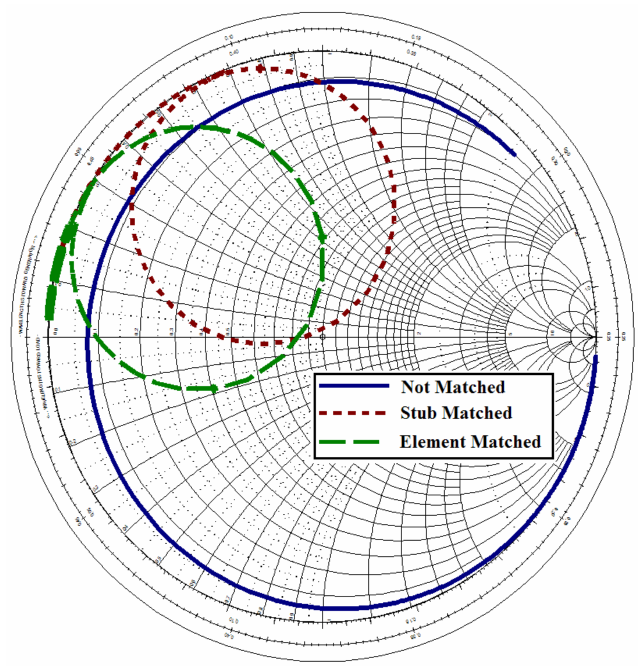


**Fig. 3. Impedance of the unmatched, stub matched and reactive element matched, random geometry wire antenna.**

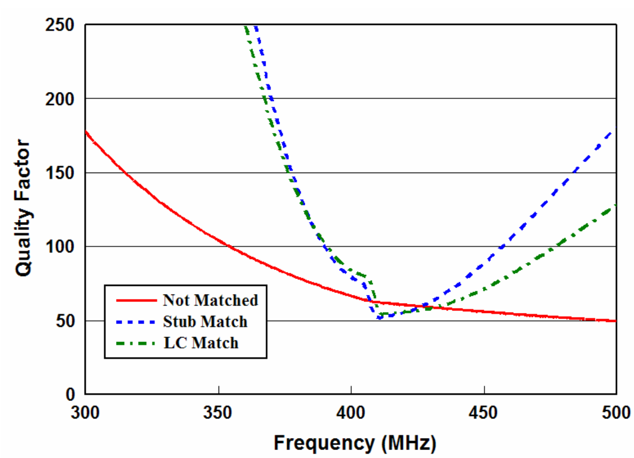


**Fig. 4. Quality Factor of the unmatched, stub matched and reactive element matched, random geometry wire antenna.**

 

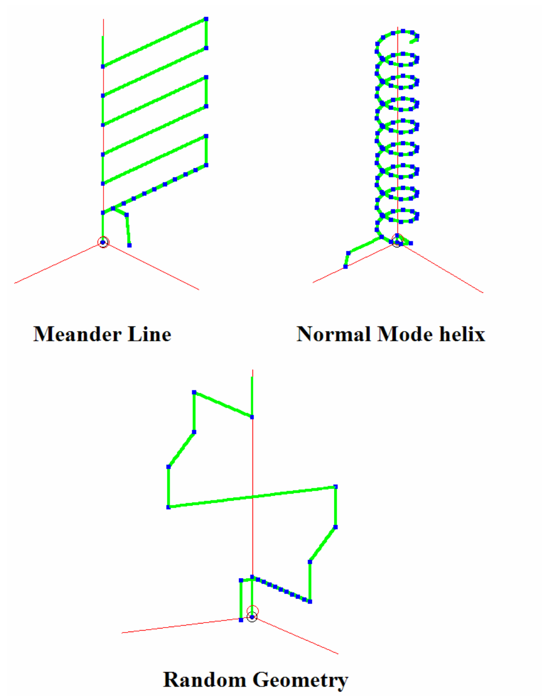


**Fig. 5. Depictions of the stub matched antennas with different geometries.**

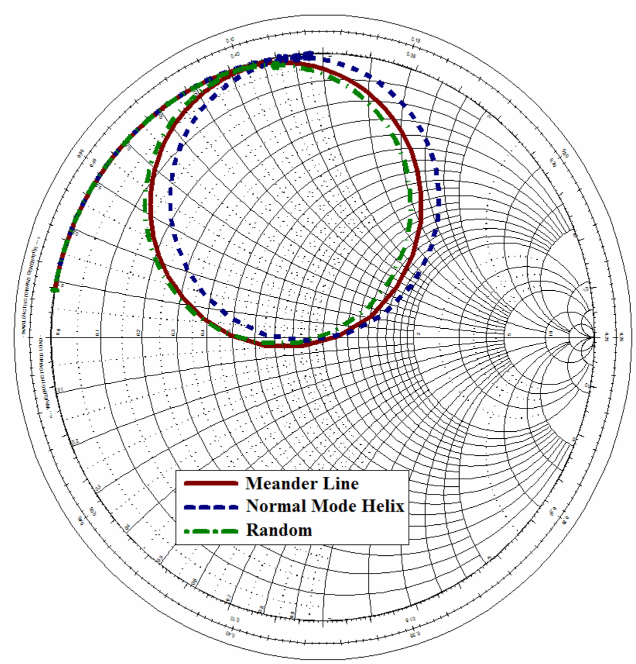


**Fig. 7. Impedance of the short-circuit stub matched meander line, normal mode helix and random geometry antennas.**

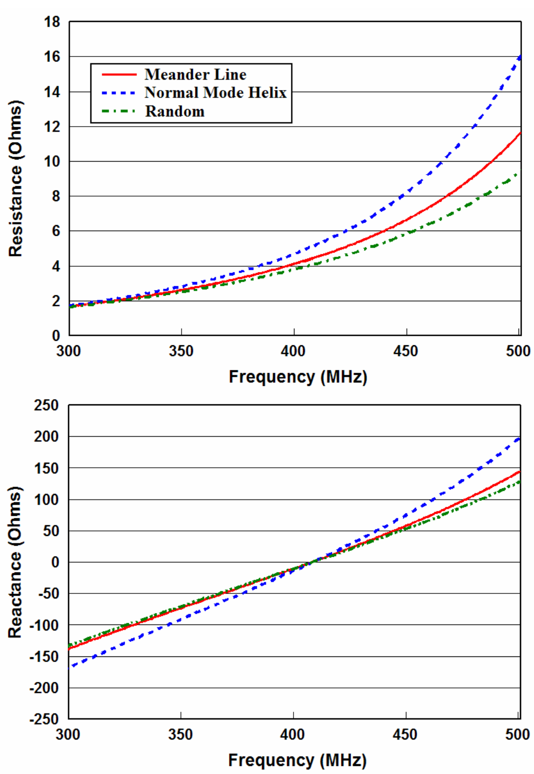


**Fig. 6. Unmatched impedance of the meander line, normal mode helix and random geometry antennas. All are made to be self-resonant at the same frequency of approximately 408 MHz.**

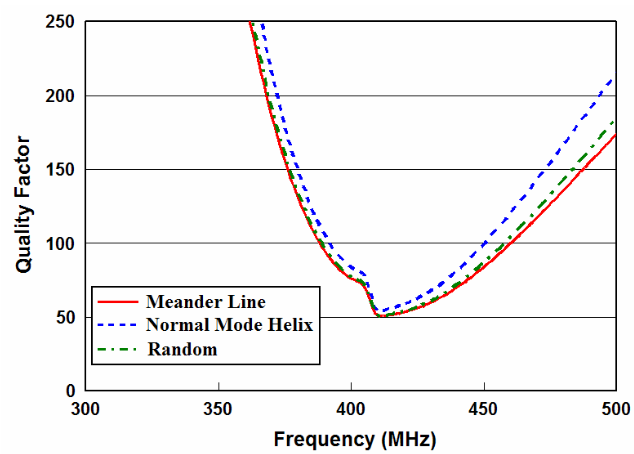


**Fig. 8. Quality Factor of the short-circuit stub matched meander line, normal mode helix and random geometry antennas.**

 